EN200

LAB #7 PRELAB

FREE SURFACE EFFECT and DAMAGE STABILITY

Instructions:

1. The first part of this lab consists of a prelab that covers the theory that will be examined experimentally during the lab.

2. The prelab is to be completed and handed in to your instructor at the beginning of the lab period.

3. If you can, answer the questions without referring to your notes. Only refer to your notes if you are confused or fail to understand a concept. This will greatly improve your understanding of the concepts this lab is designed to reinforce. Remember you will have no notes during quizzes, tests, and exams.

4. By conscientiously completing this prelab, you will have a thorough understanding of what the lab is trying to show. Your lab performance will be maximized.

5. For full credit, all work must be shown on your lab. This means that you must show generalized equations, substitution of numbers, units, and final answers. Engineering is communication. Work that is neat and shows logical progression is much easier to grade.

Student Information:

Name: ____________________________

Section: __________

Date: ____________

Aim:

- Reinforce the student's understanding of righting arm theory.
- Demonstrate the effects of a free surface on the stability of a ship.
- Demonstrate the effect that an off-centerline free surface has on the stability of a ship.
- Demonstrate how a free surface can cause a ship to become initially unstable.

Apparatus:

1. The apparatus used in this lab is exactly the same as for Labs 5 and 6. As a review, the stern view of the 27-B-1 model is shown in Figure 1. In this lab the curve of intact static stability will be constructed for three conditions:

   - A single compartment free surface tank held within the model's central compartment.
   - A double compartment free surface tank held within the model's central compartment.
   - A single compartment free surface tank combined with a transverse weight shift.

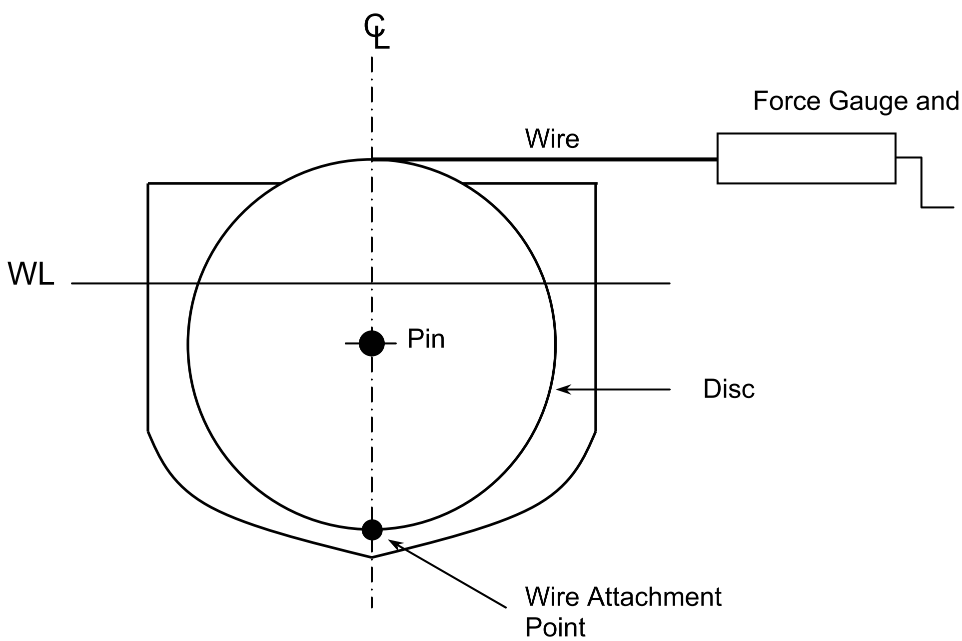

Figure 1 – Stern view of 27-B-1 apparatus

2. Once again the external force that heels the model will be produced by the wire and crank mechanism, with the magnitude of the upsetting force (F_{wire}) being measured by the force gauge. The angle of heel (ϕ) will be measured using the inclinometer.

Theory

1. Figure 2 represents the model being heeled with its associated upsetting and righting moments.

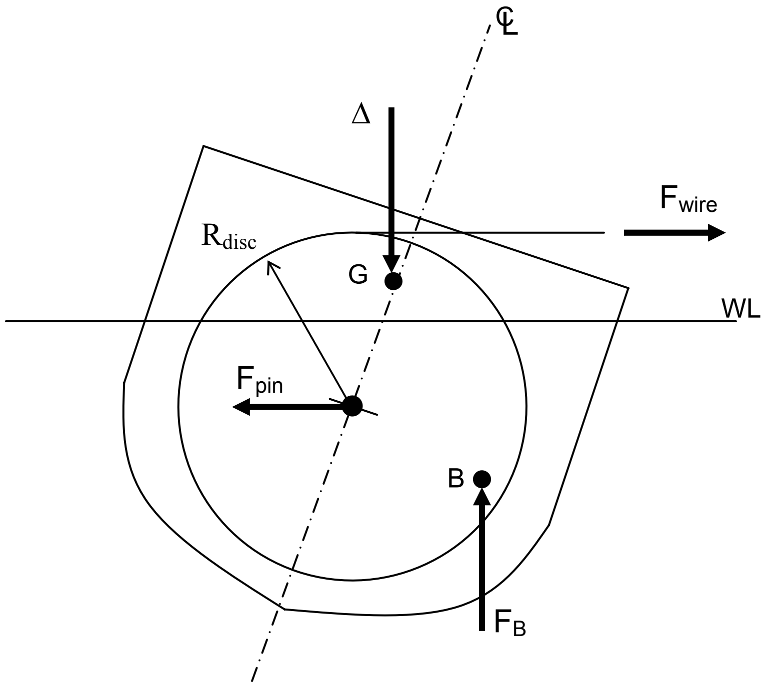

Figure 2 – Simplified view of the model being heeled

2. On this figure, draw the internal righting arm (GZ) and show the position of the metacenter (M).

3. In the box below write the equation that links the external upsetting moment to the internal righting moment and solve this equation to find an expression for the righting arm (GZ).

4. In this lab a free surface will be produced using half-full tanks of dyed water. The effect that the free surface has on the curve of intact static stability will be measured and compared with the normal loading condition. It is possible to predict this effect by an analysis of the heeling ship shown in Figure 3.

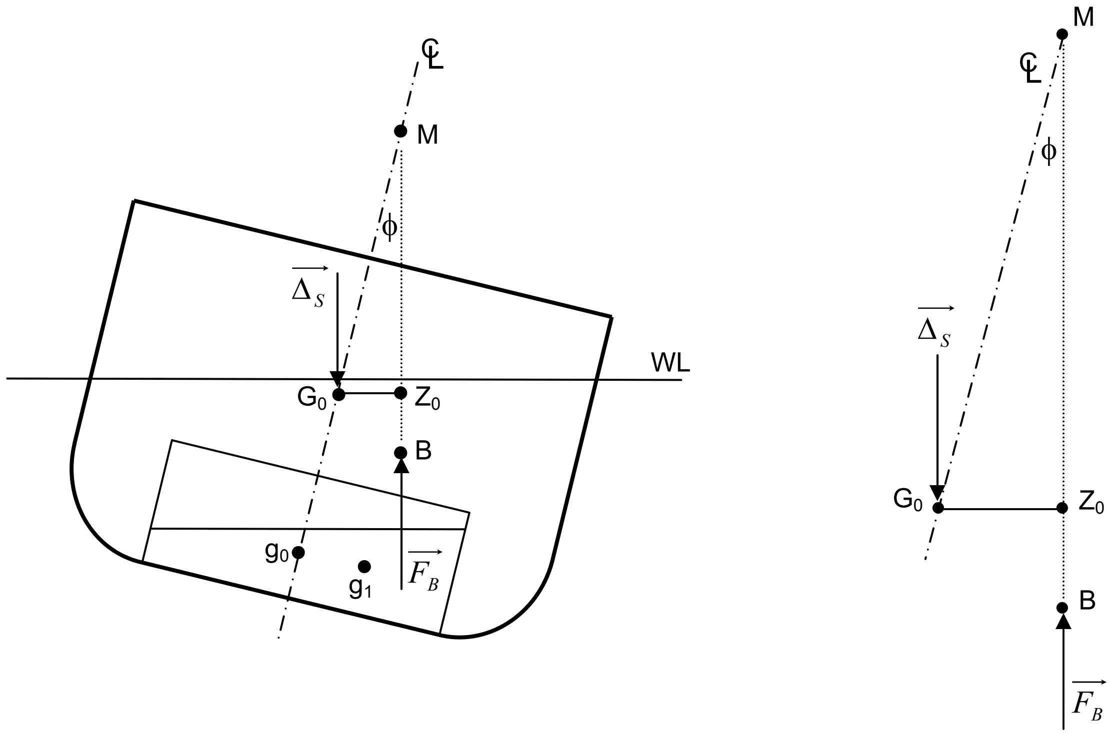

Figure 3 – Ship heeling with partially filled tank

5. On the enlarged view of the heeling diagram in Figure 3, sketch the following:

   a. The approximate location of the center of gravity of the ship created by the movement of fluid in the tank from g_0 to g_1. Label this centroid G_1.

   b. The new righting arm G_1Z_1.

6. With reference to Figure 3:

   a. What would happen to the location of G_1 if the ship were heeling by an equal amount to port?

   ____

   b. Would the overall stability be the same or different for starboard or port heeling?

   ____

7. The effect of a free surface is to cause a ship to act as if the center of gravity had been raised. Although the presence of a free surface does not cause a real rise in the center of gravity, a free surface causes a virtual rise in the center of gravity (G_V).

8. The distance G_0G_V is the virtual rise in the center of gravity and is called the "free surface correction" (FSC), and can be calculated provided the geometry of the tank's free surface and certain ship parameters are known:

$$FSC = \frac{\rho_t i_t}{\rho_S \nabla_S}$$

Complete the following table that describes the terms in this equation.

Symbol	**Description**	**Units**
ρ_t		
$\boldsymbol{i_t}$		
ρ_S		
∇_S		

9. For a tank with a rectangular free surface, the value of its 2nd moment of area about the tank centerline (i_t) is relatively easy to calculate using the equation below.

$$i_t = \frac{lb^3}{12}$$

On the plan view (top view) of the tank in Figure 4, show the quantities ***l*** and ***b***.

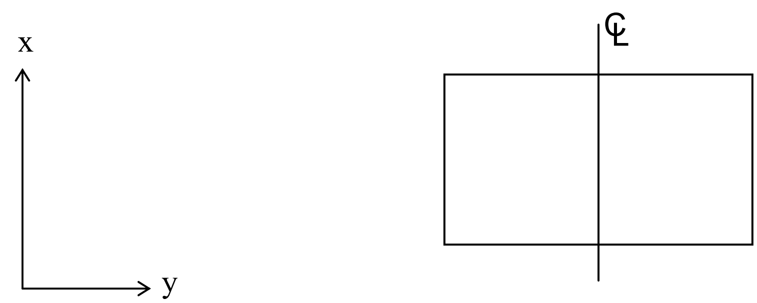

Figure 4 – Plan view of an internal free surface tank

10. The distance $G_V M$ is called the "effective metacentric height" (GM_{eff}), and the ship will exhibit stability characteristics as if this were its real metacentric height. The effective metacentric height is easy to determine provided values for KM_T, KG, and FSC are known.

Write the expression for the effective metacentric height (GM_{eff}) in terms of KM_T, KG, and FSC in the box below.

11. If the tank in Figure 3 were divided longitudinally into two tanks, how would this affect the effect of the free surface?

12. In the box below, write an expression for the effective metacentric height if the single tank in Figure 3 were divided longitudinally into two separate tanks (*tank 1* and *tank 2*).

13. In Lab 6 you saw the effect that a transverse shift in the center of gravity had on the model's stability characteristics. What effect would a transverse shift in the center of gravity combined with a free surface have on the stability of a ship?

IMPORTANT!!

Lab Preparation

1. Read through Lab 7 in its entirety.

2. Before you can begin Lab 7 you will need some information you acquired in Labs 5 and 6 concerning the model you are working with.

   Remember that you must use the same 27-B-1 model for all your labs.

   a. From Lab 5 obtain the values for Δ_{normal} and KG_{normal} and insert this data in the appropriate locations in this lab.

   b. From Lab 6 obtain the listing angle produced by the transverse shift of the 1.5 lb weight and record this value in its appropriate location in this lab.

   c. Plot the curve of intact static stability for the model in its normally loaded condition on the graph provided in this lab. This plot is required to compare the stability characteristics of the model in its normally loaded condition and its characteristics with a free surface. If you have used a computer to manipulate and plot data in Labs 5 and 6, bring a disk with your data to lab.

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EN200

LAB #7

FREE SURFACE EFFECT and DAMAGE STABILITY

Instructions:

1. This lab is conducted in the Hydro Lab on the lab deck of Rickover Hall.

2. Prior to arriving in the Hydro Lab, read through the lab procedure so that you are familiar with the steps necessary to complete the lab.

3. You will need to bring this lab and a calculator the lab period.

4. The lab is to be performed in small groups of 2 or 3. However, each member of the lab group is to submit their own work. You can ask questions and discuss the content of the lab amongst yourselves; the submitted work must be your own.

5. Follow the stages of the lab in consecutive order. The lab follows a logical thought pattern and jumping ahead without completing the intervening theory questions will limit your understanding of the concepts covered.

6. For full credit, all work must be shown on the lab. This means that you must show generalized equations, substitution of numbers, units, and final answers.

7. This lab is to be submitted at the end of the lab period. You should have sufficient time to complete the entire lab.

Student Information:

Name: ________________________________ Date: ___________

1st Partner: _____________________________

2nd Partner: _____________________________

Apparatus

1. Before beginning the experiment, ensure you are using the same model hull number as in Labs 4, 5, and 6.

   27-B-1 model number = ________________________

2. You should have three different tanks at your work station: the solid floored tank, a single compartment free surface tank, and a double compartment free surface tank.

3. Configure the model with the single 1.5 pound weight and the four 0.15 pound weights on the center post.

Initial Tasking

1. In this lab the stability of the 27-B-1 model in 3 different conditions will be compared with the model's normally loaded condition:

- With a single compartment free surface tank installed in the model's center compartment instead of the solid floor tank. The single 1.5 pound weight and four 0.15 pound weights will be on the aft centerline post. Measurements taken in this condition will be have the suffix designation "single".
- With a double compartment free surface tank installed in the model's center compartment. The deck weights remain on the aft centerline post. In this condition, all characteristics will have the suffix "double".
- Simulating a damaged condition with the single compartment free surface tank installed and the 1.5 pound weight on the starboard weight post. The four 0.15 pound weights remain on the centerline post. In this condition, all data can have the suffix "damaged".

2. For accurate comparisons to be made between the normally loaded condition and these three conditions (single, double, and damaged), the model must have approximately the same displacement and same KG at zero degrees of heel as the model in its normally loaded condition. Considering this requirement:

. Using the scale find the weight of the 3 tanks and complete the table below.

Tank	**Solid Floor**	**Single Compartment**	**Double Compartment**
Weight (lb)			

From the geometry of the three tanks would you estimate their centers of gravity to be in the same location or in different locations?

____

3. Before beginning the series of measurements, the displacement and KG of the normally loaded model as determined in Lab 5 should be recorded below:

Normally Loaded Condition	Δ_{normal} (lb)		KG_{normal} (in)	

4. From your measurements in step (2) and data copied in step (3), it should be apparent that $\Delta_{normal} = \Delta_{single} = \Delta_{double}$ and $KG_{normal} = KG_{single} = KG_{double}$. This is a necessary condition in order to make comparisons for the model under different conditions of stability.

Single Compartment Condition

5. Configure the model in its single compartment condition as follows:

   a. Single compartment free surface tank in the model's center compartment. Ensure the compartment's hatch cover is securely fastened.

   b. Four 0.15 lb weights on the aft centerline post.

   c. Single 1.5 lb weight placed on top of the 0.15 lb weights.

   d. Inclinometer mounted on the weather deck.

6. Place the model in the tank so that the pins are inserted into the tracks at each end of the tank. Set up the heeling apparatus similar to Labs 5 and 6:

   a. Connect the wire from the disk to the force gauge making sure the wire passes around the groove in the circumference of the disk.

   b. With the wire slacked (F_{wire} = 0 lb), make sure the model is floating upright. Use the adjustable transverse weights to achieve this.

   c. Zero the force gauge and ensure the red switch is in the center (neutral) detente position.

7. Read the model's forward and aft drafts and record the data in the table below:

Single Compartment Condition	
T_{fwd} (inches)	
T_{aft} (inches)	
T_{mean} (inches)	
Trim (inches)	

Heeling the Model

8. Construction of the curve of intact static stability can now begin. Perform the following steps:

   a. With the wire slacked, record the initial heeling angle and force in the wire (should be zero degrees and zero pounds).

   b. Heel the model at 5 degree increments until capsize, and read the force in the wire (F_{wire}). Record the data in the table on page 14. Ensure you note the angle at which the model capsizes.

   c. When you have heeling the model to capsize in one direction, turn the model around and heel it to capsize in the other direction. Verify the center compartment is dry, otherwise your data will have errors.

   d. When completing the data table, remember that **by convention, port distances, port heeling angles, and forces to port are negative.**

   e. Record any other observations at the bottom of the data sheet.

9. The righting arm, GZ, at each angle of heel is calculated using following relationship:

$$\overline{GZ}(in) = \frac{F_{wire}(lb) \times R_{disk}(in)}{\Delta_S(lb)}$$

In part 6 you should have deduced that: $\Delta_S = \Delta_{normal} = \Delta_{single} = \Delta_{double}$

R_{disk}, the radius of the disk, is 3 inches.

10. Plot your righting arm data for the single compartment condition on the same graph as you previously plotted the curve of intact static stability for the normal loading condition. (Graph paper is provided at the end of this lab)

You may use a spreadsheet to compute and plot the curve of intact static stability.

Remember:

Label your axes correctly
Title your plot correctly
Port measurements and angles are negative

Port Measurements		
Angle of Heel (□) (degrees)	**Force in the Wire F_{wire} (lb)**	**Righting Arm GZ (inches)**

Starboard Measurements		
Angle of Heel (□) (degrees)	**Force in the Wire F_{wire} (lb)**	**Righting Arm GZ (inches)**

Notes:

11. From your data, complete the following table:

Heeling to Port		
Condition	Normally Loaded	Single Compartment
Range of Stability (degrees)		
Maximum Righting Arm (in)		
Angle of Maximum Righting Arm (deg)		
Maximum Righting Moment (in-lb)		

Heeling to Starboard		
Condition	Normally Loaded	Single Compartment
Range of Stability (degrees)		
Maximum Righting Arm (in)		
Angle of Maximum Righting Arm (deg)		
Maximum Righting Moment (in-lb)		

12. What deduction can you make about the stability of a ship with a free surface when heeling to port? Starboard?

_______________________________________ Why? ____________________________

____

____

13. How has the presence of a free surface affected the model's dynamic stability?

____

14. In a previous lab, a decrease in stability was found when heeling to both port and starboard for a model with no free surface. What was this condition?

____

15. What happened to the center of gravity to cause this decrease in stability?

____

Free Surface Correction

16. It should be clear from your data and your answers to previous questions that the effect of a free surface is a virtual rise in the center of gravity. The amount G rises is called the 'free surface correction' (FSC).

    The free surface correction is calculated using the following equations:

$$FSC = \frac{\rho_t i_t}{\rho_S \nabla_S} \qquad \text{where: } i_t = \frac{lb^3}{12}$$

17. Remove the single compartment tank from the model. Using a ruler and the above complete the following table and calculate the free surface correction for the single compartment tank. Remember to measure only the surface of the water.

Single Compartment Tank	
l (inches) - measured along the length of the model	
b (inches) – measured along the breadth of the model	
i_t (inches^4) = $\frac{lb^3}{12}$	

18. In the box below, calculate the submerged volume of the 27-B-1 model. Assume the density of fresh water is 1.9384 lb-s^2/ft^4.

19. Calculate the FSC for the model in the single tank configuration. Assume the two densities, ρ_t and ρ_s are the same. Beware of your units!

20. Calculate the model's real metacentric height (GM_{single}) and the model's effective metacentric height (GM_{eff}).

GM_{single} =
GM_{eff} =

21. Do your calculated values of metacentric height agree with your experimental results? Why or why not?

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Reducing the Free Surface Effect

22. **Pocketing:** Pocketing occurs when the free surface reaches the tank top as the ship heels. When this happens, the size of the free surface will start to decrease, thus reducing the effect of the free surface.

    a. Observing the single compartment tank, at what angle of heel will pocketing occur?

        Pocketing Heel Angle = ____________________________________

    b. How could the free surface in the tank be caused to pocket at a lower angle of heel?

        ____

    c. By observing the data and graphs from the data, how did pocketing affect the curve of intact static stability for the single compartment condition?

        ____

        ____

23. **Tank Compartments.** Another method used to reduce the effect of a free surface is to divide tanks longitudinally into separate compartments. Although this can only be done in the design phase of shipbuilding, longitudinal division has a significant effect on the free surface correction, specifically, the second moment of area of the free surface, i_t.

a. Referring to the double compartment free surface tank, take suitable measurements and calculate the second moment of area for the double compartment tank. Note: the double compartment tank can be considered as two separate tanks.

Double Compartment Tank	
Length (l) of free surface (inches)	
Width (b) of single free surface (inches)	
i_t for a single free surface (inches^4)	
i_t for the double tank (inches^4)	

b. Calculate the free surface correction associated with the double compartment configuration.

c. Calculate the effective metacentric height of the model in its double compartment configuration.

d. Comparing the effective metacentric heights of the model in the single and double compartment conditions, which condition will have the greater initial stability? Explain your answer in terms of the relative magnitudes of the effective metacentric heights for each condition and the initial slope of the righting arm curve.

e. Compare the effective metacentric height of the model in the double compartment condition with the metacentric height of the model in the normally loaded condition. Which condition will have the greater initial stability? Why?

____

____

24. Based on your observations, what can the *ship operator do* to minimize the effect of a free surface?

____

Double Compartment Condition

25. The effects of longitudinal subdivision can now be tested by loading the double compartment free surface tank into the model and experimentally determining the righting arm curve for the model in this configuration.

26. With the double compartment tank installed in the model's center compartment and deck weights on the centerline post, heel the model to starboard and record heeling data in the table below. Ensure you record the capsize angle.

Starboard Measurements		
Angle of Heel ϕ (degrees)	**Force in the Wire F_{wire} (lb)**	**Righting Arm GZ (inches)**

Starboard Measurements Continued		
Angle of Heel ϕ (degrees)	**Force in the Wire F_{wire} (lb)**	**Righting Arm GZ (inches)**

27. **Plot** the curve of intact static stability for the model in the double compartment condition on the same axes as the normal and single compartment conditions.

28. Compare the curves of intact static stability for the model in the normally loaded, single compartment, and double compartment conditions be completing the table below.

Starboard Heel Stability Comparison			
Condition	**Normally Loaded**	**Single Compartment**	**Double Compartment**
Range of Stability (degrees)			
Maximum Righting Arm (inches)			
Maximum Righting Moment (in-lb)			
Angle of Maximum Righting Arm (deg)			

29. In which condition is the model more stable? ____________________________________

Why? ____

30. In which free surface condition is the model more stable? __________________________

Why? ____

DAMAGE STABILTY

The final portion of the lab will demonstrate the detrimental effect that a free surface located off the centerline will have on the stability of a ship.

One of the worst scenarios for ship damage with respect to stability is the presence of a free surface located off the centerline. The combined effect of a transverse weight addition and the virtual rise in the center of gravity associated with the free surface results in an exaggerated list angle and a dramatic decrease in dynamic stability that can have a dire effect on the ship's survivability.

31. From Lab 6, record the initial angle of list produced by shifting the 1.5 lb weight to starboard:

    Angle of list = ___________________________ degrees

32. To model an off-centerline free surface, configure the 27-B-1 model as follows:

    a. Place the single compartment free surface tank in the model's center compartment.

    b. Place four 0.15 lb weights on the aft centerline post.

    c. Place the 1.5 lb weight on the starboard weight post.

    You may ask how we can model an off-center free surface with the tank mounted on the model's centerline. Recall that the location of a free surface is independent of the free surface correction.

33. Record the model's initial angle of list in the damaged condition: ___________________

34. What has caused the increase in the angle of list from the angle recorded in Lab 6?

    ____

    ____

35. Heel the model through its range of stability to find its curve of intact static stability in the damaged condition and record heeling data in the table on the following page. Do only starboard heeling angles.

Starboard Measurements		
Angle of Heel ϕ (degrees)	**Force in the Wire F_{wire} (lb)**	**Righting Arm GZ (inches)**

Starboard Measurements Continued		
Angle of Heel ϕ (degrees)	**Force in the Wire F_{wire} (lb)**	**Righting Arm GZ (inches)**

36. Plot the curve of intact static stability for the model in the damaged condition on the same axes as the other plots in this lab.

37. From your data, complete the following table.

Starboard Heel Stability Comparison			
Condition	**Normally Loaded**	**Single Compartment**	**Damaged Condition**
Range of Stability (degrees)			
Maximum Righting Arm (inches)			
Maximum Righting Moment (in-lb)			
Angle of Maximum Righting Arm (deg)			

38. How has the off-center free surface condition affected the model's stability? Explain your answer in terms of righting arm, righting moment, range of stability, and dynamic stability.

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38. As you have seen in this lab, flooding damage located off the centerline has a detrimental impact on ship stability. For reasons that should be obvious, the top priority of shipboard damage control is the isolation of floods, water removal, and restoration of ship stability, "floods before fires".

Counterflooding, the intentional flooding of a tank or compartment on the opposite side of the ship, is occasionally used to restore a ship to an even keel, lower the center of gravity, and increase metacentric height (restore stability). However, counterflooding can produce the opposite effect and render the ship even less stable. Based on your knowledge of hydrostatics and ship stability, why could counterflooding be hazardous to ship survivability?

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